# TARDEC

# Technical Report

**No. 13640**

# Evaluation of Environmentally Acceptable Hydraulic Fluids

**March 1995**



By In-Sik Rhee
Carlos Velez
Karen Von Bernewitz
USA Tank Automotive Command
Mobility Technology Center Belvoir



Distribution unlimited; approved for public release.

COMMITTED TO EXCELLENCE

U.S. Army Tank-Automotive Command
Research, Development and Engineering Center
Warren, Michigan 48397-5000

# REPORT DOCUMENTATION PAGE

*Form Approved OMB No. 0704-0188*



**1. AGENCY USE ONLY** *(Leave blank)*

**2. REPORT DATE**
March 1995

**3. REPORT TYPE AND DATES COVERED**
Final October 1993 to September 1994

**4. TITLE AND SUBTITLE**
Evaluation of Environmentally Acceptable Hydraulic Fluids (U)

**5. FUNDING NUMBERS**

**6. AUTHOR(S)**
In-Sik Rhee, Carlos Velez, and Karen Von Bernewitz

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
U.S. Army Tank-Automotive RD&E Center
Mobility Technology Center - Belvoir
ATTN: AMSTA-RBF
10105 Gridley Rd, Ste 128
Fort Belvoir, Virginia 22060-5843

**8. PERFORMING ORGANIZATION REPORT NUMBER**
TARDEC-TR-13640

**9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)**
CDR Defense General Supply Center
ATTN DGSC-SHP
8000 Jefferson Davis Hwy
Richmond, VA 23297-5678

**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**

**11. SUPPLEMENTARY NOTES**

**12a. DISTRIBUTION/AVAILABILITY STATEMENT**
Distribution unlimited; approved for public release.

**12b. DISTRIBUTION CODE**

**13. ABSTRACT** *(Maximum 200 words)*
This describes the laboratory evaluation of environmentally acceptable (EA) commercial hydraulic fluids formulated with vegetable oils and synthetic esters. Evaluations included viscosity, flammability, corrosion and wear protection, thermal and oxidation stability, low temperature capability, elastomer compatibility, and storage stability. Results showed the vegetable based products were limited in operational temperature ranges (-10°C to 90°C) due to poor thermal and low temperature stabilities. On the other hand, synthetic ester based fluids showed a wide operational capability (-40°C to 150°C) which can meet the requirements of military mobile hydraulic fluids. Although EA hydraulic fluids did not meet the current military specification requirements, they are potentially good candidate fluids for the replacement of some current petroleum based military hydraulic fluids.

**14. SUBJECT TERMS**
Environmentally Acceptable Hydraulic Fluid
Biodegradability
Toxicity
Vegetable Oil

**15. NUMBER OF PAGES** 26

**16. PRICE CODE**

| 17. SECURITY CLASSIFICATION OF REPORT | 18. SECURITY CLASSIFICATION OF THIS PAGE | 19. SECURITY CLASSIFICATION OF ABSTRACT | 20. LIMITATION OF ABSTRACT |
|---|---|---|---|
| Unclassified | Unclassified | Unclassified | UL |

No. 13640

# Evaluation of Environmentally Acceptable Hydraulic Fluids

## March 1995




By In-Sik Rhee
Carlos Velez
Karen Von Bernewitz
USA Tank Automotive Command
Mobility Technology Center Belvoir

# Contents

| | | Page |
|---|---|---|
| **Section 1** | **Background/Objective** | **1** |
| **Section 2** | **Approach** | **2** |
| **Section 3** | **Market Survey** | **3** |
| **Section 4** | **Test Results** | **6** |
| **Section 5** | **Conclusions/Recommendations** | **14** |
| **References** | | **15** |

**Tables**

1. Test Protocol for EA Hydraulic Fluid Evaluation ........ 2
2. Domestic Environmental Acceptable Hydraulic Fluids ........ 3-4
3. Comparison of Base Fluids ........ 5
4. Environmental Acceptable (EA) Hydraulic Fluids – Physical Property Data ........ 9-13

# Section 1 Background/Objective

In recent years there has been an increasing interest in Environmentally Acceptable (EA) Hydraulic Fluids, especially among agricultural, construction, forestry, lumber, and mining industries where involuntary or accidental fluids leakage or spillage is detrimental to the environment. In response to the demand for EA hydraulic fluids, a number of lubricant suppliers have developed EA hydraulic fluids which are less toxic and more biodegradable than currently used hydraulic fluids. Although there are many military applications for which the current EA hydraulic fluids are not useable, it is possible that some of these products can be used for some military applications. Technical evaluation is needed to determine how they perform according to current military requirements.

Most EA hydraulic fluids were formulated with vegetable oils (rapeseed, sun flower, corn, canola) and synthetic ester, such as the polyol ester. The vegetable oils are becoming more important than synthetic ester based oils because of their availability and low cost. Typically, rapeseed oil based fluids have excellent lubricating properties and biodegradability.[1] The potential benefits for use of EA hydraulic fluids are to reduce the quantity of hazardous waste being generated and to lower disposal costs although current EPA rulings no longer classify used oils as hazardous waste. However, a demand for biodegradable oils is coming from California, Texas and Florida, because of their more stringent state regulatory requirements. A pressing need to use biodegradable oils is to eliminate the hazardous pollution caused by accidental oil spillage, which is especially important in environmentally sensitive applications. Another good reason to use biodegradable, vegetable/synthetic ester based oils is to develop a market for US grown agricultural feedstocks and to reduce reliance on overseas petroleum crude oil.

The following hydraulic fluids were identified as having some potential for biodegradable basestocks application since their requirements for low temperature operability and long-term storage stability are not critical.

| | |
|---|---|
| VV-C-850[2] | *Cutting Fluids, Sulfurized Fatty and Mineral Oils* |
| MIL-H-17672[3] | *Hydraulic Fluid, Petroleum, Inhibited* |
| MIL-H-46001[4] | *Hydraulic Fluid, Petroleum Base, for Machine Tools* |

To determine whether EA hydraulic fluids would be suitable in military applications, a market study was initiated by the Fuels and Lubricants Division of the U.S. Army's Mobility Technology Center, Fort Belvoir VA with funding provided by the Defense Environmental Restoration Account (DERA), managed by the HAZMIN Office of the Defense Logistics Agency (DLA) located at Defense General Supply Center (DGSC), Richmond, Virginia.

The objective of this project is to evaluate currently available EA hydraulic fluids to determine their performance according to current military specifications. If test results indicate that the EA hydraulic fluids meet current military specification requirements, recommendations for specification amendments will be provided to the appropriate preparing activities. If they do not meet any current military specifications, suppliers will be queried as to the possibility of developing EA hydraulic fluids which could meet military requirements.

# Section 2 Approach

A market survey for EA hydraulic fluids was conducted within the United States. The approach used in this survey was to review technical data sheets and current technology used in EA hydraulic fluids, and to determine availability of EA hydraulic fluids including manufacturers. For evaluation, the samples of EA hydraulic fluids were collected and a test plan was developed based on the requirements of military hydraulic fluids. Typical tests performed on all samples were viscosities, pour point, flash point, corrosion protection, corrosiveness and oxidation stability, thermal stability, lubricity, accelerated storage stability and elastomer swell. Hydraulic pump testing and environmental tests (i.e., biodegradability, toxicity) were not included under this testing program due to the unavailability of test equipment. The test protocol is listed in Table 1.

**Table 1. Test Protocol for EA Hydraulic Fluid Evaluation**

| Test | Method |
|---|---|
| Viscosity, Kinematic | ASTM D 445 |
| Viscosity index | ASTM D 2270 |
| Pour point | ASTM D 97 |
| Flash point | ASTM D 92 |
| Fire point | ASTM D 92 |
| Neutralization number | ASTM D 664 |
| Galvanic corrosion | FED-STD 7915,#5322 |
| Rust prevention | ASTM D 665 |
| Foaming | ASTM D 892 |
| Thermal stability | Cincinnati Milacron |
| Elastomer compatibility, NBR-L | FED-STD 791,#3603 |
| API, Specific Gravity | ASTM D 287 |
| Water content | ASTM D 1744 |
| Evaporation @ 100 °C, 1 hr | Thermogravimetric Analysis (TGA) |
| Copper corrosion @ 100°C, 3 days | ASTM D 130 |
| Corrosiveness & Oxidative Stability, 100 °C | ASTM D 4636 |
| Low temperature stability, -15 °C, 72 hrs | FED-STD 791,#3458 |
| Humidity Cabinet corrosion, 720 hrs | ASTM D 1748 |
| Lubricity | ASTM D 4172 |
| Oxidation stability, Pressure Differential Scanning Calorimeter (PDSC) | Modified ASTM D 5483 |
| Storage stability @ 100 °C, One month | Army method |

To compare with military hydraulic fluids, MIL-H-46001 was selected as a reference sample because most samples received have been designed as industrial hydraulic fluids. For this reason, MIL-H-46001 hydraulic fluid was also tested to provide baseline comparison data. The VV-C-850 cutting oil and MIL-H-17672 hydraulic fluids were not selected as a reference sample because of their initial design criteria. In fact, VV-C-850 oil was originally formulated to use as cutting fluid in the machining of metals, while MIL-H-17672 fluids was designed to use in shipboard hydraulic systems.

# Section 3 Market Survey

Environmental safety and compliance has become the most significant worldwide issue in oil industry in recent years. The use of EA hydraulic fluids in mobile and industrial hydraulic systems is becoming the first among many to resolve environmental pollution problems. For this reason, the lubricants industry and equipment manufacturers have shown increased interest in the development of EA hydraulic fluids because of high demand and government legislation. In the United States, market potential for EA hydraulic fluids is expected to grow with the increase of environmental regulations. Table 2 lists EA hydraulic fluids that are commercially available. Currently, there are three types of EA hydraulic fluids available. These types of fluids are either vegetable oil based, synthetic polyglycol based or synthetic ester based. Each of these fluids has characteristics that differ from conventional mineral oil.

**Table 2. Domestic Environmental Acceptable Hydraulic Fluids**

| Product Name | Basestock | Description | Company Name | Address |
|---|---|---|---|---|
| EL 146 | Seed oil + mineral oil | Readily biodegradable and non-toxic ISO 46 hydraulic oil for use in heavy duty hydraulic systems. | EarthRight Technologies | 33307 Curtis Blvd. Eastlake, OH 44095 |
| Plantohyd 40 | Rapeseed + sulfurized fatty vegetable oil | Universal, multigrade hydraulic oil for agricultural, forestry, and construction machinery | Fuchs Metal Lubricants Company | Metal Lubricants Co., 17050 Lathrop Avenue, Harvey, IL 60426 |
| Functional 9403071 | Rapeseed | Biodegradable, corrosion inhibited, antiwear hydraulic oils for mobile, industrial & marine hydraulic systems | Greenoco, Functional Products, Inc. | Functional Products, Inc., 24000 Merchantile Road, Unit 5, Cleveland, OH 44122 |
| Greenwood Hydraulic Fluids | Vegetable; rapeseed | Biodegradable, corrosion inhibited, antiwear hydraulic oils for mobile, industrial & marine hydraulic systems | Greenoco, Inc. | The Green Oil Company Company, P.O. Box 577, Blue Bell, PA 19422 |
| HYD271, 272 | Vegetable; canola | Biodegradable, corrosion, antiwear and oxidation inhibited hydraulic oils for industrial hydraulic systems | International Lubricants, Inc. | International Lubricants, Inc., 7930 Occidental South, Seattle, WA 98108 |
| Mobil EAL 224H | Vegetable; rapeseed | Biodegradable, antiwear, corrosion protective hydraulic oil for moderate or severe operating conditions. | Mobil Oil | Mobil Oil Corporation 3225 Gallows Road Room 5W806, Fairfax, VA 22037-0001 |
| Mobil XRL 1711-78 | Synthetic ester | Antiwear, corrosion protective hydraulic oil. | Mobil Oil | Mobil Oil Corporation 3225 Gallows Road Room 5W806, Fairfax, VA 22037-0001 |
| Quintolubric 822-220,330, 450 | Polyol ester | Fire resistant hydraulic fluid to replace phosphate esters | Quaker Chemical Corp. | Quaker Chemical Corp Conshohocken, PA 19428-0809 |
| HVO-46 Hydraulic Vegetable Oil | Vegetable | For hydraulic systems that require both antiwear and rust and oxidation properties | Renewable Lubricants, Inc. | 476 Griggy Road P.O. Box 474 Hartville, OH 44632 |

**Table 2. Domestic Environmental Acceptable Hydraulic Fluids (continued)**

| Product Name | Basestock | Description | Company Name | Address |
|---|---|---|---|---|
| Royco 3100, 3046, RTJ 27, RTJ 41 | Polyol ester | Biodegradable, antiwear hydraulic fluids | Royal Lubricants | Royal Lubricants Company, Inc., P.O. Box 518, Merry Lane, E. Hanover, NJ 07936 |
| OS 107086 | Sunflower oil | Based on Sunyl PF 311; Sunflower oil with alkylated phenol | SVO Specialty Products, Inc. | SVO Specialty Products, Inc., 35585-B Curtis Blvd., Eastlake, OH 44095 |
| OS 106575 | Sunflower oil | Based on SUNYL PF 311; Sunflower oil | SVO Specialty Products, Inc. | SVO Specialty Products, Inc., 35585-B Curtis Blvd., Eastlake, OH 44095 |
| Biostar Hydraulic 46, Code 1616 | Rapeseed; Ethyl hexyl oleate, c18 fatty acids | Environmentally friendly, zinc free, antiwear oil for high pressure hydraulic equipment | Texaco | Texaco Lubricants Company, North America, P.O. Box 4427, Houston, TX 77210-4427 |
| Synstar Hydraulic 46, Code 2073 | Trimethyl-propane (TMP) & Penta-erythritol ester blend, BHT | Environmentally friendly, zinc free, antiwear oil for high pressure hydraulic equipment | Texaco | Texaco Lubricants Company, North America, P.O. Box 4427, Houston, TX 77210-4427 |
| Terra-Lube ECO 2000 | Natural esters, Triglycerides | Biodegradable and non-toxic natural ester based universal hydraulic fluid designed for use in all equipment | CoChem, Inc. | CoChem, Inc. 7555 Bessemer Ave. Cleveland, OH 44127 |
| Calgene Q1093, 1094, 1095 | Rapeseed, Canola oil | Vegetable oils based VI Index, wear and oxidation additives | Calgene Chemical, Inc. | Calgene Chemical, Inc. 7247 N. Central Park Ave. Skokie, IL 60076-4093 |
| Clark Cone oil | Cone oil | Environmentally friendly product | CoChem, Inc. | CoChem, Inc. 7555 Bessemer Avenue Cleveland, OH 44127 |

Vegetable oils have excellent lubrication qualities and are nontoxic and biodegradable. They are made from renewable resources such as rapeseed, sunflower, corn, canola and are much less expensive than synthetic fluids. Their chemical structure are triglycerides in which a variety of saturated, monounsaturated or poly unsaturated fatty acids are esterified to a glycerol backbone. The physical properties of a vegetable oil depend on the nature of its fatty acid composition. The disadvantages of these oils are well known, two of which are poor low temperature fluidity and rapid oxidation at elevated temperatures.[6]

Polyglycol oils are the oldest biodegradable fluids and have been used in construction machinery, the vicinity of ground water, and the food processing industry. Currently, the usage of these fluids tend to decline due to the tendency to be aquatically toxic when admixed with lubricating additives and the incompatibility with mineral oils and other materials such as elastomers.[7]

Synthetic esters, mainly based on trimethylolpropane, polyol ester and pentaerythritol, are regarded as the best among the biodegradable base fluids. The biodegradability of these oils is comparable to vegetable oils and their lubrication properties are very similar to mineral oils. The advantages of these oils are excellent fluidity , and low temperature and aging stabilities. On the other hand, the cost of synthetic esters are much higher than those of mineral oils.[8] Their differences are summarized in Table 3.

**Table 3. Comparison of Base Fluids**

| | Mineral Oils | Vegetable Oils | Synthetic Esters | Poly-Glycol |
|---|---|---|---|---|
| Biodegradability CEC-L33-T82, % | 10-40 | 70-100 | 10-100 | 10-90 |
| Viscosity Index | 90-100 | 100-250 | 120-220 | 100-200 |
| Pour Point, °C | -54 to -15 | -20 to 10 | -60 to -20 | -40 to 20 |
| Compatibility with Mineral Oils | – | Good | Good | Not miscible |
| Oxidation Stability | Good | Poor to Good | Poor to Good | Poor |
| Relative Cost | 1 | 2 to 3 | 5 to 20 | 2 to 4 |

EA Hydraulic fluids also require additive to enhance performance. The lubrication properties of some vegetable oils such as rapeseed oil and synthetic esters can be improved by antioxidants, corrosion inhibitors and pour point stabilizers. However, the use of conventional additives in EA hydraulic fluids may pose potential problems on the fluid's biodegradability and ecotoxicological properties due to the toxicity of chemicals. Thus, the domestic additive manufacturers are also investing in developing the EA additives which are compatible with EA hydraulic fluids. Some EA additives such as sulphur-carriers have been developed and are currently available in the domestic market.

# Section 4 Test Results

A total twenty-six samples were received from fourteen oil companies. Most fluids were designed as industrial hydraulic fluids, and were formulated with vegetable oils (rapeseed, sunflower, corn, canola) and synthetic ester such as polyol ester. These types of base oils are currently used in EA hydraulic fluids because of their biodegradable characteristics. To assess EA fluids, all samples were tested according to the limited testing program. Table 4 summarized the results of tests which were conducted through in-house laboratory testing which included accelerated storage stability test. Code letters have been used to protect the identities of the samples submitted.

Viscosity is the most important property in selecting hydraulic fluids. This property directly affects flow characteristics, heat generation within system, pumping operation, sealing, leaking characteristics. Currently, military hydraulic systems use four different types of viscosity grades (ISO VG 32,46,68 and 150). The viscosity of most samples were measured within ISO viscosity grades 32 and 46 ranges. Based on these results, the availability of other types of viscosity grades seems to be no problem. Viscosity Index (VI) is used for measure of how viscosity changes with temperatures. All samples had very high VI indexes which exceeded the minimum VI index limit (90) of MIL-H-46001 specification. Generally, a high VI indicates that the viscosity of fluids undergo less change with temperature variations. In the low temperature (-15 °C) viscosity tests, most EA hydraulic fluids flowed in capillary tubes while some vegetable fluids had difficulty to flow due to their poor low temperature properties.

Pour point is defined as the lowest temperature at which oil flows when chilled under specified test condition and is used for determining low temperature operation limits of hydraulic fluids. The MIL-H-46001 specification requires a minimum of -12 °C pour point in grades 1, 2 and 3 and a minimum of -6 °C for grade 4. These types of industrial hydraulic fluids were originally formulated to use in machine shops which are not sensible to cold environment. The test results showed that all samples met the specification requirements. To verify these results, the low temperature stability tests were conducted at -15 °C for 72 hours. Nineteen samples were clear and remained as liquid while some vegetable oils froze. It appeared that the low temperature stability of vegetable based fluids are poor compared to mineral oils because they consist of a wide range of fatty acid ester. However, the synthetic ester based fluids did not have any low temperature stability problems at this test temperature.

Lubricity is the degree to which fluids lubricate moving parts and minimize wear within a system. Most hydraulic fluids often contain anti-wear additives to improve wear prevention properties. This property is usually evaluated in the Four Ball Wear test. To assess the effectiveness of anti-wear additives in EA hydraulic fluids, the four ball wear tests were performed according to ASTM D2266, Wear Preventive Characteristics of Hydraulic Fluids. The test results indicated that all samples tested provided good wear properties which can be compared with that of MIL-H-46001 fluid.

Flash and fire points of hydraulic fluids do provide a rough characterization relative to their flammable nature. Almost all samples exceeded to the MIL-H-46001 specification requirements and provided a much lower flammability than that of MIL-H-46001 fluid. Also, the evaporation tests showed that EA fluids did not have a volatility problem. It appeared that EA fluids exhibit excellent inherent fire resistance characteristics over the conventional petroleum based hydraulic fluids.

To assess the corrosion properties of EA fluids, five different types of corrosion tests were performed: copper corrosion test, galvanic corrosion test, rust prevention test in synthetic seawater, humidity cabinet test, and corrosiveness and oxidation stability test. These corrosion tests were originally designed to evaluate specific corrosion characteristics of fluids in different applications and environments. The galvanic corrosion and rust prevention tests are currently used in industrial hydraulic fluid specifications such as MIL-H-46001 while other three corrosion tests are used for evaluating mobile hydraulic fluids such as military tactical hydraulic fluids. The test results showed that most EA samples failed in galvanic corrosion tests while two-third of samples passed the rust prevention tests. In copper corrosion tests, most samples provided excellent corrosion protection against copper metal and showed a comparable performance to that of MIL-H-46001 fluid. Humidity cabinet tests showed that a majority of EA fluids tested provide better corrosion protection than MIL-H-46001 fluid. The ASTM D4636 test method measures corrosiveness and oxidation stability of fluids. In this test, most EA fluids failed in corrosion tests and some vegetable fluids became polymerized during tests due to their poor thermal stability.

The oxidation stability of EA hydraulic fluids are one of the important operational parameters in military hydraulic systems. To evaluate this property, Pressure Differential Scanning Calorimetry (PDSC) tests were conducted. This method is currently being developed to assess oxidation stability of lubricating oils in service and storage conditions. The test results showed that vegetable oil based fluids give poor oxidation stability while synthetic ester fluids provide the same quality of oxidation stability of petroleum based fluids. It appeared that vegetable based fluids are applicable to use in moderate operation temperatures (below 90 °C).

Measurement of water content is also important in relation to corrosion prevention and oxidation resistance properties of fluids. The test results showed that most samples had a higher water content than MIL-H-46001 fluid. A high water content in fluids may affect to fluid life and cause corrosion problems in hydraulic systems.

The thermal stability of industrial hydraulic fluids is currently comprehensively evaluated based on the changes in appearance, neutralization number, and viscosity of the fluid. In the Cincinnati Milacon thermal stability test,[9] vegetable oils showed a poor thermal stability. These results also agreed with those of corrosiveness and oxidation stability tests.

Foaming is attributed to mechanical operating conditions producing turbulence in the presence of air or water. Excessive foaming of fluids result in decreasing lubrication effectiveness and create maintenance problems in hydraulic system. The test results indicated that most EA fluids do not have foaming problems.

Seals have sometimes failed to perform their designed function of retaining hydraulic fluids and excluding contaminants because of incompatibility between the seal elastomer and the hydraulic fluid. The deterioration of elastomer seals results in the failure of hydraulic power and causes leaking of fluids. To prevent this problem, elastomer compatibility tests were performed using the reference elastomer (NBR-L). Most EA fluids provided an abnormal behavior when compared to the MIL-H-46001 product.

Hydraulic fluids generally change in prolonged storage. If the change results in product falling out of specification range or causes performance to be below standard, that change is noteworthy and can be disturbing. Prior to use, this property must be determined. To evaluate this property, an accelerated storage stability test was conducted at 100 °C for one month duration. The evaluation method used in this test was to compare MIL-H-46001 requirements with fluid based on viscosity, acid number and oxidation induction time changes. The test results showed that some vegetable oils have a short storage life due to their poor oxidation and thermal stability at elevated temperatures.

## Table 4. Environmental Acceptable (EA) Hydraulic Fluids - Physical Property Data

**EA HYDRAULIC FLUIDS - VISCOSITY, GRAVITY, WEAR PREVENTION**

| Product Code | Viscosity, 100°C, cSt | Viscosity, 40 °C, cSt | Viscosity, -15°C, cSt | Viscosity Index | Pour Point, °C | API Gravity | Specific Gravity | Lubricity, 40kg, Scar Diam, mm |
|---|---|---|---|---|---|---|---|---|
| MIL-H-46001 Specification Requirements | Report | Grade 1:28.8-35.2<br>Grade 2:41.4-50.6<br>Grade 3:61.2-74.8<br>Grade 4:135-165 | NR[1] | 90 (min) | -12 (max)<br>-12<br>-12<br>-6 | 30-33<br>28-32<br>29-31<br>27-30 | NR | NR |
| A | 8.45 | 39.50 | 3204.3 | 155 | -18 | 22.3 | 0.92 | 0.34 |
| B | 9.82 | 46.15 | 819.4 | 155 | -30 | 21.47 | 0.925 | 0.51 |
| C | 10.6 | 50.46 | 1829.7 | 154 | -30 | 22.3 | 0.92 | 0.44 |
| D | 8.34 | 37.08 | 2230.5 | 160 | -27 | 25.72 | 0.9 | 0.46 |
| E | 7.97 | 35.87 | 951.5 | 161 | -30 | 22.3 | 0.92 | 0.5 |
| F | 8.97 | 41.55 | 1298.3 | 155 | -24 | 22.3 | 0.92 | 0.47 |
| G | 8.23 | 39.17 | 649.8 | 154 | -18 | 22.0 | 0.922 | 0.55 |
| H | 6.27 | 33.08 | 878.6 | 135 | -17 | 24.0 | 0.910 | 0.39 |
| I | 10.8 | 50.6 | 758.1 | 155 | -26 | 24.17 | 0.9088 | 0.67 |
| J | 14.28 | 66.1 | 1136.0 | 155 | -26 | 23.82 | 0.9107 | 0.66 |
| K | 19.3 | 94.6 | 2084.3 | 150 | -26 | 21.97 | 0.9220 | 0.53 |
| L | 9.58 | 49.13 | 1103.9 | 148 | -36 | 24.0 | 0.910 | 0.4 |
| M | 13.62 | 96.55 | 4456.0 | 128 | -54 | 7.2 | 1.02 | 0.42 |
| N | 7.61 | 43.49 | 1256.7 | 132 | -57 | 10.0 | 1.0 | 0.45 |
| O | 3.44 | 12.24 | 145.6 | 169 | -58 | 24.0 | 0.91 | 0.87 |
| P | 9.92 | 48.48 | 1035.1 | 152 | -36 | 22.3 | 0.92 | 0.44 |
| Q | 9.52 | 38.08 | 988.9 | 167 | -36 | 24.0 | 0.910 | 0.39 |
| R | 10.54 | 48.8 | 911.1 | 156 | -29 | 21.47 | 0.925 | 0.43 |
| S | 9.67 | 50.43 | 1125.0 | 147 | -45 | 22.0 | 0.922 | 0.49 |
| T | 9.76 | 45.05 | 817.4 | 157 | -34 | 22.3 | 0.92 | 0.81 |
| U | 9.41 | 44.48 | 1340.1 | 155 | -24 | 22.3 | 0.92 | 0.6 |
| V | 9.66 | 46.68 | 2309.4 | 153 | -24 | 22.3 | 0.92 | 0.57 |
| W | 9.69 | 44.88 | 1463.0 | 147 | -15 | 22.3 | 0.92 | 0.73 |
| X | 2.56 | 8.13 | 77.0 | 151 | -65 | 27.4 | 0.89 | 0.85 |
| Y | 8.08 | 35.24 | 1359.0 | 161 | -18 | 22.3 | 0.92 | 0.73 |
| MIL-H-46001 | 5.29 | 31.43 | 1543.7 | 99 | -39 | 31.1 | 0.87 | 0.43 |

*1. Not required*

## Table 4. Environmental Acceptable (EA) Hydraulic Fluids - Physical Property Data (continued)

**EA HYDRAULIC FLUIDS - OTHER BASIC PROPERTIES**

| Product Code | Oxidation Stability[2], min | Low Temp Stability, 72 hrs, -15°C | Evaporation Loss[3], % (100°C, 1 hr) | Flash Point, °C | Fire Point, °C | Water Content, ppm | Swell of Synthetic NBR-L Rubber, % | Foaming, Seq. I, II, III | Neutralization Number mg KOH/g |
|---|---|---|---|---|---|---|---|---|---|
| MIL-H-46001 Specification Requirements | NR | NR | NR | Grade 1: 188<br>Grade 2: 196<br>Grade 3: 196<br>Grade 4: 221<br>(min) | 216<br>218<br>218<br>246<br>(min) | NR | NR | Pass | 1.5 (max) |
| A | 29.0 (155 °C) | white solid | 0.18 | 310 | 362 | 238 | 9.16 | pass | 0.43 |
| B | 45.45 (130 °C) | cloudy, crystals, flowing flowing | 0.78 | 200 | 320 | 248 | 11.34 | fail | 0.33 |
| C | 9.31 (130 °C) | flowing, clear | 0.01 | 264 | 352 | 183 | 11.29 | pass | 0.60 |
| D | 4.65 (130 °C) | flowing, clear | 0.06 | 260 | 358 | 257 | 11.86 | pass | 0.79 |
| E | 12.1 (155 °C) | flowing, clear | 0.03 | 310 | 340 | 202 | 10.8 | pass | 0.13 |
| F | 31.96 (130 °C) | flowing, clear | 0.25 (gain) | 294 | 340 | 232 | 14.07 | fail | 3.04 |
| G | 14.3 (155 °C) | flowing, clear | 1.15 | 316 | 362 | 309 | 34.18 | pass | 1.32 |
| H | 15.43 (180 °C) | flowing, clear | 1.2 | 260 | 272 | 125 | 33.06 | pass | 0.96 |
| I | 17.9 (180 °C) | flowing, clear | 0.2 | 268 | 320 | 347 | 26.46 | pass | 2.04 |
| J | 20.6 (180 °C) | flowing, clear | 0.23 | 270 | 320 | 392 | 25.46 | pass | 2.43 |
| K | 14.84 (180 °C) | flowing | 0.17 | 270 | 366 | 380 | 17.74 | pass | 3.09 |
| L | 13.34 (180 °C) | milky, solid | 0.78 | 278 | 335 | 124 | 10.35 | pass | 1.35 |
| M | 60.9 (210 °C) | flowing, clear | 0.3 | 278 | 282 | 463 | 35.99 | pass | 0.42 |
| N | 43.3 (210 °C) | flowing, clear | 0.13 | 264 | 288 | 330 | 42.42 | pass | 0.42 |
| O | 38.6 (180 °C) | flowing, clear | 4.51 | 186 | 190 | 543 | 39.4 | fail | 0.22 |
| P | 13.85 (180 °C) | milky, solid | 1.0 | 294 | 334 | 217 | 10.27 | pass | 1.08 |
| Q | 30.57 (155 °C) | milky, solid | 0.4 | 296 | 344 | 356 | 11.8 | pass | 1.47 |
| R | 25.08 (155 °C) | flowing | 0.86 | 276 | 302 | 151 | 14.28 | pass | 1.21 |
| S | 28.7 (155 °C) | flowing, clear | 1.48 | 260 | 340 | 175 | 16.07 | pass | 2.14 |
| T | 30.73 (155 °C) | flowing, crystal forming | 1.3 | 264 | 348 | 212 | 12.6 | pass | 0.24 |
| U | 4.62 (130 °C) | flowing, clear | 0.01 (gain) | 314 | 358 | 304 | 20.42 | pass | 2.82 |
| V | 3.09 (130 °C) | flowing | 0.14 (gain) | 318 | 352 | 272 | 18.07 | pass | 1.49 |
| W | 6.75 (130 °C) | milky, solid | 0.23 | 338 | 364 | 335 | 8.56 | pass | 0.4 |
| X | 43.6 (180 °C) | flowing, clear | 7.5 | 180 | 185 | 480 | 41.19 | ND | 0.27 |
| Y | 9.0 (155 °C) | milky, solid | 0.13 (gain) | 316 | 360 | 178 | 10.85 | ND | 0.07 |
| MIL-H-46001 | 24.2 (180 °C) | flowing, clear | 0.75 | 212 | 234 | 125 | 7.78 | fail | 0.58 |

2. *Pressure Differential Scanning Calorimeter (PDSC)*
3. *Thermogravimetric Analysis (TGA)*

## Table 4. Environmental Acceptable (EA) Hydraulic Fluids - Physical Property Data (continued)

EA HYDRAULIC FLUIDS - CORROSION TESTS

| Product Code | Copper Corrosion (3 days, 100°C) | Galvanic Corrosion | Rust Prevention, Synthetic Seawater (ASTM D665) | Humidity Cabinet, Hrs. to Fail | Corrosiveness and Oxidation stability (ASTM D4636, 100°C) |
|---|---|---|---|---|---|
| MIL-H-4001 Specification Requirements | NR | Pass | Pass | NR | NR |
| A | 1a | fail, pitting | pass | 203 | fail |
| B | 4c | fail, slight pitting | pass | >720 | fail |
| C | 1b | fail, pitting | fail w/polymerization | 187 | fail |
| D | 2c | fail, pitting | fail, severe rust | 96 | fail |
| E | 1a | fail, pitting | fail, rust | >720 | fail |
| F | 1b | fail, pitting | fail, rust | >720 | fail |
| G | 1a | fail, slight pitting | pass | 66 | fail |
| H | 1a | fail, slight pitting | pass with discoloration | 66 | fail |
| I | 1a | pass | pass | >720 | fail (121°C) |
| J | 1a | pass | pass | >720 | fail (121 °C) |
| K | 1a | fail, slight pitting | pass | >720 | fail (121 °C) |
| L | 1b | pass | pass with polymerization | 230 | pass |
| M | 1b | fail, pitting | ND | 240 | pass |
| N | 1b | fail, pitting | pass | 104 | pass |
| O | 1b | pass | pass | 232 | fail |
| P | 1b | fail, pitting | pass | >720 | pass |
| Q | 1b | fail, pitting | pass | >720 | fail |
| R | 1a | fail, slight pitting | pass | >720 | fail |
| S | 2c | fail, slight pitting | pass | >720 | fail |
| T | 1b | pass | pass | >720 | pass |
| U | 2c | fail, pitting | fail, rust | >720 | fail |
| V | 1a | pass | fail, rust | >720 | fail |
| W | 2c | fail, pitting | fail, rust | 252 | fail |
| X | 1b | pass | pass | 504 | pass |
| Y | 3a | fail, pitting | ND | 21 | fail |
| MIL-H-46001 | 1a | pass | pass | 48 | pass |

**Table 4. Environmental Acceptable (EA) Hydraulic Fluids - Physical Property Data (continued)**

**EA HYDRAULIC FLUIDS - CINCINNATI MILACRON THERMAL STABILITY TEST, PROCEDURE A**

| Product Code Steel Rod | % Vis Change Copper Rod | Neutralization # Change, mg KOH/g | Precipitate or sludge, mg/100 mL | Steel Rod | | | Copper Rod | |
|---|---|---|---|---|---|---|---|---|
| | | | | Visual Condition | Deposit, mg | Metal Removed, mg/200 mL | Visual Condition | Deposit, mg |
| MIL-H-46001 Spec Requirements | +5 (max) | Grade 1,2,3: +0.75 Grade 4: 0.15 | 25 (max) | Report | 3.5 (max) | 1.0 (max) | 5 | 10 (max) |
| A | +5.27 | 1.9 | 8.6 | like new | 5.5 | 1.9 | 2c | 1.2 |
| B | +46.8 | 1.29 | 49.2 | slight tarnish | 0.3 | nil | 1a, sludge | nil |
| C | +19.02 | 1.44 | 12.25 | slight tarnish | 0.4 | nil | 4b | 2.4 |
| D | +14.9 | 1.19 | 11.45 | slight tarnish | 0.9 | nil | 4a | 0.6 |
| E | +11.12 | 6.27 | 10.85 | slight tarnish | nil | nil | 1a | 0.6 |
| F | +13.76 | 4.72 | 17.75 | slight tarnish | nil | nil | 1a | 2.1 |
| G | +9.79 | 2.49 | 3.6 | slight tarnish | 0.4 | nil | 1a | nil |
| H | +2.75 | 1.61 | 1.2 | slight tarnish | 0.5 | nil | 1b | nil |
| I | -4.73 | 0.05 | 32.35 | medium tarnish | 0.5 | nil | 3a | 0.3 |
| J | -1.97 | 0.39 | 17.35 | medium tarnish | 0.7 | nil | 2c | 0.7 |
| K | -0.35 | 1.08 | 10.3 | medium tarnish | 0.2 | nil | 3b | 6.9 |
| L | +4.38 | 0.15 | 15.65 | slight tarnish | 1.5 | nil | 2c | 7.4 |
| M | -37.39 | 1.74 | 22.15 | slight tarnish | 1.8 | nil | 2e | 1.1 |
| N | -0.39 | 3.38 | 10.95 | slight tarnish | 1.8 | 0.3 | 3a | 0.4 |
| O | +16.91 | 0.82 | 3.95 | slight tarnish | 1.0 | 0.4 | 3a | 0.7 |
| P | +7.65 | 0.7 | 12.20 | medium tarnish | 2.5 | 0.3 | 4a | 1.1 |
| Q | +30 | 0.38 | 9.6 | medium tarnish | 0.4 | nil | 1b | 0.9 |
| R | +0.10 | 3.61 | 11.45 | slight tarnish | 0.6 | 0.9 | 2c | nil |
| S | +5.39 | 0.93 | 11.85 | slight tarnish | 0.4 | 0.3 | 3a | nil |
| T | +10.41 | 3.65 | 27.15 | slight tarnish | 0.7 | nil | 4a | 2.2 |
| U | +172.57 | 0.39 | 18.95 | slight tarnish | 2.3 | nil | 1a | 2.4 |
| V | +175.86 | 2.09 | 37.3 | slight tarnish | 1.7 | 0.6 | 1a | 1.8 |
| W | +82.22 | 0.9 | 28.35 | slight tarnish | 2.0 | nil | 1b | 1.2 |
| X | +6.77 | 2.04 | 5.6 | slight tarnish | 1.5 | nil | 1b | 1.0 |
| Y | +50.17 | 0.35 | 192.15 | slight tarnish | 1.7 | nil | 1b | 1.7 |
| MIL-H-46001 | +7.45 | 0.49 | 8.75 | medium tarnish | nil | nil | 4b | 5.6 |

**Table 4. Environmental Acceptable (EA) Hydraulic Fluids - Physical Property Data (continued)**

**EA HYDRAULIC FLUIDS - ACCELERATED STORAGE STABILITY (100 °C, ONE MONTH)**

| Product Code | Viscosity Changes, %, 40 °C | Acid Number Changes, mg | PDSC, Induction Time Changes, % |
|---|---|---|---|
| A | +0.9 | 0.29 | -5.0 |
| B | +16.2 | 1.67 | -27.66 |
| C | +25.0 | 2.74 | -16.0 |
| D | +2.3 | 1.85 | -8.0 |
| E | +18.9 | 2.7 | -48.1 |
| F | +21.1 | 1.55 | 0 |
| G | -3.0 | 2.4 | 0 |
| H | -0.4 | 1.08 | 0 |
| I | -8.3 | 1.76 | 0 |
| J | -4.5 | 1.43 | -12.6 |
| K | -3.3 | 1.62 | 0 |
| L | +0.83 | 0.1 | 0 |
| M | -0.85 | 1.94 | -9.6 |
| N | -2.64 | 2.09 | -16.75 |
| O | -0.25 | 0.45 | -22.0 |
| P | -0.6 | 1.53 | 0 |
| Q | -0.8 | 1.69 | 0 |
| R | -2.3 | 2.46 | -11.56 |
| S | -0.9 | 2.31 | 0 |
| T | +19.93 | 0.98 | -9.5 |
| U | +19.72 | 1.41 | -68.0 |
| V | +50.28 | 0.05 | 0 |
| W | +76.6 | 0.69 | -73.48 |
| X | -0.62 | 0.36 | -51.83 |
| Y | +74.4 | 0.98 | -87.55 |
| MIL-H-46001 | +1.43 | 0.03 | -25.58 |

# Section 5 Conclusions/Recommendations

On the basis of the work completed to date, EA hydraulic fluids can be used in selected military industrial applications. Most fluids tested were very close to meeting requirements of MIL-H-46001 specification and are promising as the candidate EA military hydraulic fluids. The results of this study are summarized in the following finding:

- Numerous EA hydraulic fluids are currently available in domestic market and new products are being developed.
- EA hydraulic fluids are biodegradable and less toxic products, and were formulated using vegetable oils (rapeseed, sunflower, corn, canola) and synthetic esters.
- Vegetable based EA hydraulic fluids were limited in operational temperature ranges (-10 °C to 90 °C) due to poor thermal and low temperature stabilities. On the other hand, synthetic ester based fluids showed a wide operational capability (-40 °C to 150 °C) which can meet the requirements of military mobile hydraulic fluids.
- Humidity cabinet test results showed that EA hydraulic fluids provide better corrosion protection than current military hydraulic fluids. EA fluids also showed good performance in the copper corrosion test and rust prevention test using synthetic sea water. In the corrosiveness and oxidation stability tests, most EA fluids failed due to their poor oxidation stability.
- PDSC tests showed that vegetable oil based fluids give poor oxidation stability while synthetic ester based fluids provide the same quality of oxidation stability of petroleum based fluids.
- EA fluids provided high flash and fire points over petroleum based fluid. Also, they did not show any evaporation and foaming problems.
- Elastomer compatibility tests showed that EA fluids might be incompatible with certain types of elastomers.
- EA fluids provided good wear properties which can be compared with petroleum based fluid.
- Accelerated storage stability tests showed that some vegetable based fluids had a short storage life due to their poor oxidation and thermal stability at elevated temperatures.

Although EA hydraulic fluids did not meet the current military specification requirements, they are potentially good candidate fluids for the replacement of some current petroleum based military hydraulic fluids which create environmental problems. Based on the market survey, further development of EA fluid is highly recommended.

# References


1. A.A Wessol and Bill Whitacre "Operating Hydraulics Green Fluids", Machine Design, January 1993.

2. Federal Specification VV-C-850 Amendment-1, Cutting Oils; Sulfurized Fatty and Mineral, 26 September 1968.

3. Military Specification MIL-H-17672, Hydraulic Fluid, Petroleum, Inhibited, 23 January 1984.

4. Military Specification MIL-H-46001, Hydraulic Fluids, Petroleum Based, For Machine Tools, 7 December 1989.

5. Federal Test Method Standard No. 791C, Lubricants, Liquid Fuels, and Related Products; Methods of Testing, 30 September 1986.

6. Hans F. Eichenberger "Biodegradable Hydraulic Lubricants and Overview of Current Developments in Central Europe", 42nd Annual SAE Earthmoving Industry Conference, April 1991.

7. V.M Cheng and A.A Wessol "Biodegradable and Nontoxic Hydraulic Oils", 42nd Annual SAE Earthmoving Industry Conference, April 1991.

8. E.M. Stempfel, L.A. Schmid, and Aseol AG "Biodegradable Lubricating Greases, NLGI Spokesman, November 1991.

9. Cincinnati Milacron Marketing Company, Special Manual, Lubricants Purchase Specifications, Approved Products, Publication Number 10-SP-80160 (undated)

# Distribution for TARDEC Technical Report 13640

**DEPARTMENT OF THE ARMY**

CDR AMC
1 ATTN AMCRD S
5001 EISENHOWER AVE
ALEXANDRIA 22333-0001

TARDEC
1 ATTN AMSTA TR-R
1 ATTN AMSTA TR-M
1 ATTN AMSTA TR-E
1 ATTN AMSTA TR-K
1 ATTN AMSTA TR-NAC
WARREN MI 48397-5000

TARDEC
50 MOBILITY TECHNOLOGY CENTER BELVOIR
ATTN AMSTA RBF
10115 GRIDLEY RD STE 128
FT BELVOIR VA 22060-5843

CDR ARMY TACOM
1 ATTN AMSTA IM-LMT
1 ATTN AMSTA IM-LMM
1 ATTN AMSTA IM-LMB
1 ATTN AMSTA IM-FR
1 ATTN AMSTA IM-FT
1 ATTN AMSTA IM-KP
1 ATTN AMSTA IM-MC
1 ATTN AMSTA IM-MT
1 ATTN AMCPM-CE
1 ATTN AMCPM-M113
1 ATTN AMCPM-T
WARREN MI 48397-5000

PROGRAM MANAGER
1 COMBAT MOBILITY SYS
ATTN SFAE-ASM-CV
WARREN MI 48397-5000

PROGRAM MANAGER
1 ARMORED GUN SYS
ATTN SFAE-ASM-AG
WARREN MI 48397-5000

PROGRAM MANAGER
AFAS/FARV MOB SYS
1 ATTN SFAE-FAS-AF-CS
WARREN MI 48397-5000

CDR APC
1 ATTN SATPC Q
1 ATTN SATPC QE (BLDG 85 3)
NEW CUMBERLAN, PA 17070-5005

1 PETROL TEST FAC WEST
BLDG 247 TRACEY LOC
DDRW
P O BOX 96001
STOCKTON CA 95296-0960

CDR ARMY TECOM
1 ATTN AMSTE TA R
1 ATTN AMSTE TC V
1 ATTN AMSTE EQ
APG MD 21005-5006

PROG EXEC OFFICER
ARMAMENTS
1 ATTN SFAE AR HIP
1 ATTN SFAE AR TMA
1 PICATINNY ARSENAL, NJ 07806-5000

DIR
ARMY RSCH LAB
1 ATTN AMSRL CP PW
2800 POWDER MILL RD
ADELPHIA MD 20783-1145

CDR AEC
1 ATTN SFIM AEC ECC (T ECCLES)
APG MD 21010-5401

CDR ARMY ARDEC
1 ATTN SMCAR CC
1 ATTN SMCAR ESC S
PICATINNY ARSENAL, NJ 07808-5000

CDR ARMY DESCOM
1 ATTN AMSDS MIN
1 ATTN AMSDS EN
CHAMBERSBURG PA 17201-4170

CDR ARMY AMCCOM
1 ATTN AMSMC MA
ROCK ISLAND IL 61299-6000

CDR ARMY WATERVLIET ARSN
1 ATTN SARWY RDD
WATERVLIET NY 12189

CDR ARMY FIELD ARTY SCH
1 ATTN ATSF CD
FT SILL OK 73503

CDR ARMY ENGR SCHOOL
1 ATTN ATSE CD
FT LEONARD WOOD, MO 65473-5000

CDR ARMY CERL
1 ATTN CECER EN
PO BOX 9005
CHAMPAIGN IL 61826-9005

CDR
RED RIVER ARMY DEPOT
1 ATTN SDSRR M
1 ATTN SDSRR Q
TEXARKANA TX 75501-5000

**DEPARTMENT OF THE NAVY**

CDR
NAVAL RSCH LABORATORY
1 ATTN CODE 6176 (R. MOWERY)
4555 OVERLOOK AVENUE, SW
WASHINGTON DC 20032

CDR
NAVAL SEA SYSTEMS CMD
1 ATTN SEA 03M3
2531 JEFFERSON DAVIS HWY
ARLINGTON VA 22242-5160

CDR
NAVAL SURFACE WARFARE CTR
1 ATTN CODE 632
1 ATTN CODE 859
3A LEGGETT CIRCLE
ANNAPOLIS MD 21401-5067

1 OFC ASST SED NAVY (17E)
CRYSTAL PLAZA 5
2211 JEFFERSON DAVIS HWY
ARLINGTON VA 22244-5110

**DEPARTMENT OF THE NAVY/U.S MARINE CORPS**

1 PROG MGR COMBAT SER SPT
MARINE CORPS SYS CMD
2033 BARNETT AVE STE 315
QUANTICO VA 22134-5080

CDR
MARINE CORPS LOGISTICS BA
1 ATTN CODE 837
814 RADFORD BLVD
ALBANY GA 31704-1128

CDR
BLOUNT ISLAND CMD
1 ATTN CODE 922/1
JACKSONVILLE FL 32226-3404

**DEPARTMENT OF AIR FORCE**

AIR FORCE WRIGHT LAB
1 ATTN WL/POSL
1790 LOOP RD N
WRIGHT PATTERSON AFB
OH 45433-7103

AIR FORCE WRIGHT LAB
1 ATTN WL/MLBT
2941 P ST STE 1
WRIGHT PATTERSON AFB, OH 45433-7718

AIR FORCE WRIGHT LAB
1 ATTN WL/MLSE
2179 12TH ST STE 1
WRIGHT PATTERSON AFB, OH 45433-7718

1 WR ALC/LVRS
225 OCMULGEE CT
ROBINS AFB, GA 31098-1647

**DEPARTMENT OF DEFENSE**

ODUSD
1 ATTN (ES) CI
400 ARMY NAVY DR
STE 206
ARINGTON VA 22202

DEFENSE GEN SUPPLY CTR
1 ATTN DGSC SSA
1 ATTN DGSC STA
8000 JEFFERSON DAVIS HWY
RICHMOND VA 23297-5678

12 DEFENSE TECH INFO CTR
CAMERON STA
ALEXANDRIA VA 22304

**INDUSTRY**

1 EARTH RIGHT TECHNOLOGIES
ATTN MR. CARMINE CAMINO
33307 CURTIS BLVD
EASTLAKE, OH 44095

1 METAL LUBRICANTS CO.
ATTN MR. JOE MANFREDA
17050 LATHROP AVENUE
HARVEY, IL 60426

1 FUNCTIONAL PRODUCTS, INC.
ATTN MR. FRED LITT
24000 MERCANTILE ROAD, UNIT 5
CLEVELAND, OH 44122

1 THE GREEN OIL CO.
ATTN MR. IRA PIERCE
P.O. BOX 577
BLUE BELL, PA 19422

1 INTERNATIONAL LUBRICANTS, INC.
ATTN DR. ALKA SHANAHAN
7930 OCCIDENTAL SOUTH
SEATTLE, WA 98108

1 MOBIL OIL CORPORATION
ATTN MR. ALLAN WESSOL
3225 GALLOWS ROAD
ROOM 5W806
FAIRFAX, VA 22037-0001

1 QUAKER CHEMICAL CORP.
ATTN MR. PAUL QUINN
CONSHOHOCKEN, PA 19428-0809

1 RENEWABLE LUBRICANTS, INC.
ATTN MR. WILLIAM GARMIER
476 GRIGGY ROAD
P.O. BOX 474
HARTVILLE, OH 44632

1 ROYAL LUBRICANTS CO.
ATTN MS. RENEE KOENEN
P.O. BOX 518
MERRY LANE
E. HANOVER, NJ 07936

1 SVO SPECIALTY PRODUCTS, INC.
ATTN DR. CHOR HUANG
35585-B CURTIS BLVD.
EASTLAKE, OH 44095

1 TEXACO LUBRICANTS CO.
ATTN MR. GREG FERNANDEZ
P.O. BOX 4427
HOUSTON, TX 77210-4427

1 COCHEM INC.
ATTN MR. DAVY SUKYS
7555 BESSEMER AVENUE
CLEVELAND, OH 44127

1 CALGENE CHEMICAL INC.
ATTN MR. CHANDU PATTER
7247 NORTH CENTRAL PARK AVE.
SKOKIE, IL 60076-4093